THE ATLANTA BEELINE

Invertebrate Pollinator Corridor Suitability Analysis of the Metropolitan Atlanta Region

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Introduction

As evidenced by numerous studies, invertebrate pollinator species are in decline worldwide. The implications of this trend are numerous and potentially catastrophic. Pollination services derived from these creatures provide benefits such as food, plant-derived medicines, ecosystem resilience, and economic development where agriculture is a large part of the economy. Pollinator-dependent plants, by definition, require pollination services to survive and much of our agriculture relies on their continuous support for successful food production. As managed honey bee colonies continue to decline, it is necessary to start valuing and supporting the arguably more important contributions that wild pollinator services offer. Consequently, this valuation relies on understanding the causes of pollinator declines, the costs associated with pollinator decline, and the mitigation methods that could successfully reverse the process. There are over 4,400 species of native bees identified in North America, but this study focuses on the habitat preferences of the genus Bombus, or bumble bees, as they represent some of the most important and effective bees in the eastern United States. Of these 21 eastern bumble bee species, six are experiencing drastic population declines (13). Planning for pollinator population support has become critically important. Some studies have estimated the pollinator value for crop production in Georgia to be $608 million, which is significantly greater than the reported $14 million value of honey bee rentals (1).

Furthermore, as a leading cause of pollinator decline has been attributed to habitat loss and fragmentation, it is becoming apparent that efforts need to be made to conserve and connect suitable food resources and nesting habitats that can support pollinator populations. The significance of the population declines afflicting our native pollinators has made it crucial to create a framework to support urban planners and policy makers in identifying and protecting large scale networks of pollinator habitats using empirically based data and GIS.

Previous studies on habitat suitability analysis for pollinators have relied on field survey data to bolster and assess the accuracy of analyses, yet this type of fieldwork requires resources that may often be unattainable for planners and policy makers. Considering the dire state of pollinator population declines, it has become important to identify tools and methods accessible to these fields which can assist in pollinator conservation efforts. Invertebrate habitat suitability assessment has historically required approaches based on proxies and surrogates due to the elusive nature of these animals. Methodologies historically include mapping based on species-habitat associations, spatial heterogeneity assessment based on primary productivity, temporal heterogeneity assessment, structural property mapping, and mapping of chemical attractants to extrapolate species richness and abundance. The purpose of this paper is to illustrate the use of empirical research, GIS, species habitat associations, and spatial heterogeneity to determine the most suitable location for a protected, connective pollinator corridor in the context of urban planning without the use of field work.

Background

The European honey bee has recently received a great amount of media attention due to Colony Collapse Disorder and widespread population declines. However, less well known is the parallel population loss occurring in native bee species. Bees pollinate about 70 percent of global crops, many of which are of high economic value. Crops requiring insect pollination include but are not limited to alfalfa, almonds, apples, blackberries, canola, cherries, cranberries, pears, plums, squash, sunflowers, tomatoes, peppers, and watermelons (13). Moreover, the free ecological services performed by native bees can enhance agricultural productivity and crop quality, even in some plants that do not require pollinator pollination services (9). As in the case of California's Central Valley watermelons, if 30 percent of the area within 1.2 kilometers of the field is left as natural bee habitat then native bees can provide all pollination services for those crops when the farmer would otherwise have to pay for costly imported honey bee services. Particularly important is the efficient native bumble bee (23).

According to The Xerces Society for Invertebrate Conservation, it would require 15,000 to 20,000 honey bees to effectively pollinate an acre of apples while the more specialized native orchard mason bee could perform the same task with only 250 bees. Such specialization of native bees for certain types of flowers also induces more successful results for their produce, such as larger and more abundant fruit (10). Even fruits that don't require pollination services to reproduce can benefit from bumble bees and other bees that perform buzz pollination, a highly effective vibration behavior not used by honey bees. Furthermore, many will forage under a wider and less optimal range of conditions than honey bees and many plants are dependent on the services of bumble bees for existence (13).

Bees represent keystone species in nearly all ecosystems in which they exist. Other than agricultural services, bees pollinate wild plants that provide forage and habitats for numerous animal species such as some birds and bears. They serve to maintain biological and genetic ecosystem diversity and represent crucial indicators of ecosystem health. Furthermore, pollinator services are of great agricultural and economic value. Native bees in Costa Rica, for example, have been shown to increase coffee yields by 20% when their habitats were located within just one kilometer of the coffee fields. The economic value of their pollination services was $60,000 per 1,100 hectares between the years 2000 and 2003 (23). Notably, native bumble bees are highly valuable generalist pollinators and second only to honey bees in terms of global economic contributions (1).

Threats to Native Bees

Threats to native bees are numerous and not yet well understood. Main culprits most likely include habitat loss and fragmentation, agricultural intensification, grazing, pesticide exposure, diminished genetic diversity, competition with honey bees, exotic pathogens, and climate change. In Europe, habitat fragmentation is considered the main cause of bumble bee declines, while in North America the leading cause is thought to be the intensification of agricultural uses of land (10). Considering the fact that bumble bees require generally undisturbed nesting and hibernation sites at ground level or lower, farming practices such as plowing and mowing can destroy these critical habitats. Additionally, the implementation of extensive amounts of monoculture land uses, as well as overgrazing by livestock, have destroyed vast grasslands that once provided plentiful forage resources (17).

Vulnerability to extinction caused by habitat loss is compounded by the nature of bumble bee life cycles and genetic characteristics. Bees are haplodiploid organisms, meaning that sex determination results from the queen either fertilizing or abstaining from fertilizing her eggs. Fertilized eggs are diploid and become females while unfertilized eggs are haploid and become males. However, when colony populations are small and isolated, the queen becomes more likely to mate with genetically similar males. This can disrupt egg development and cause fertilized eggs to develop into males. If this occurs frequently enough it can result in an inadequate amount of female workers and new queens and ultimately reduce colony resilience to the point of nonexistence; males are essentially a cost to the colony as they do not forage for food or contribute to rearing of larvae yet they consume food resources (27).

Unsurprisingly, widespread and often unregulated use of insecticides and herbicides pose a real threat to all insect pollinators. By definition, insecticides kill insects; herbicides reduce plant species richness. Bees are exposed to pesticides via crops, rangelands, recreational areas, gardens, and numerous other landscapes. Due to ease of accessibility, lack of regulation, and limited educational opportunities, the highest rates of pesticides, in pounds per acre, are dispersed by homeowners in urban and suburban areas. Notably, practices aimed at avoiding pesticide exposure to honey bees by spraying early in the morning may actually result in increased exposure to bumble bees due to their increased activity in cooler temperatures and lower lighting (26).

Insecticide overspray and drift can result in die offs of bystander insects as well as disturbed cognitive functioning, lower reproductive success, and loss of pollination services. Neonicotinoids and other systemic pesticides are particularly threatening to bees and have been cited as a likely cause of the dramatic decline of pollinator populations that began in the 1990s. Studies have shown that even low doses are highly toxic and can dramatically decrease queen production in bumble bees. Furthermore, even many pesticides that have acquired approval for organic agriculture can be harmful to bees (25). More cautious policies regarding pesticide approval, clear product labeling, as well as risk management and assessment to bees in various life stages are badly needed.

Herbicides reduce plant diversity, nesting sites, and food sources. As pollinators and their plant communities are mutually dependent on each other for survival, this loss of resources can result in declining bee populations. Selective application based on availability of food sources and mechanical plant removal can be implemented as alternative methods to reduce negative impacts.

Commercial use of bumble bees comprises a particularly significant threat to North American bumble bees. For example, queen bumble bees were sent to Europe in the early 1990s to be reared for commercial purposes and resulting colonies were then shipped back to the United States. Multiple factors support the hypothesis that while in the commercial facilities, the bees contracted a European fungal pathogen called Nosema bombi. Commercial bees frequently escape from greenhouses and open fields and, upon the bees' re-entrance into the U.S., severe declines in several species of wild bumble bee populations ensued (28). Four of these species are now critically imperiled (4). Problematically, commercial uses of bumble bees as pollinators are becoming increasingly popular throughout the world. Commercialization of bee colonies poses a meaningful threat to wild bees as well as managed colonies, as the consequences of pest and disease transmission from regional or global trade can be rapid, widespread, and potentially very severe. The common eastern bumble bee (Bombus impatiens) is the only Bombus species currently used in commercial pollination (13). As it is native to the eastern United States, the risk of pathogen transmission and habitat competition for wild bumble bees in the western U.S. is substantial.

On a similar note, native bumble bees also face competition with the European honey bee. Introduced to America in the early seventeenth century, honey bees now play a large part in U.S. agriculture. Unfortunately, honey bees have also been shown to cause reduced foraging efficiency and worker size in bumble bees as well as diminished reproductive success (29). One honey bee hive can extract hundreds of pounds of nectar in just one year, which can put pressure on nearby bees relying on the same resources for food. This pressure is compounded when the landscape is already limited in pollen and nectar sources or experiencing seasonal or phenological vegetation scarcities. Furthermore, honey bees have been shown to not only alter bumble bee foraging times, but to physically displace the bees from flowers, thereby reducing foraging efficiency (14). Finally, as pollen can act as a vector for disease, bumble bees are at an increased risk of pathogen infection in areas where honey bees share the same floral food sources (30). This type of disease transmission can be minimized by imposing restrictions on the placement of honey bee hives such that they are not located in sensitive natural areas where biodiversity is desired.

Climate change-related alterations pose another threat to bees. Flowering phenology, temperature, and precipitation changes could likely result in habitat and forage loss. As sufficient resources are crucial when reproductive members are developing, bumble bees will be most vulnerable to nectar and pollen availability shifts during these critical periods at the beginning and end of the life cycle.

Habitat Requirements

Bumble bees require three habitat typologies, including forage sources for pollen and nectar, nesting sites, and hibernation sites. Nest sites are often found in abandoned rodent burrows underground, abandoned bird nests, tufts of grass, under piles of rock, or in cavities of dead trees (13). Additionally, as bumble bees are uniquely capable of thermoregulation, they tend to thrive in colder temperatures than other bees such as those found in northern climates and at high elevations.

Proper vegetation availability is necessary for the establishment of valuable pollinator forage habitat. Having coevolved with native bees, vegetation should ideally be comprised of a diverse selection of native sources of nectar and pollen. These plants typically require less maintenance and landowners enjoy reduced costs associated with water and chemical applications. Additionally, they typically provide sufficient nutrients that are often inaccessible or absent in flowers bred purely for aesthetic value (31). Bumble bees have exhibited preferences for purple, blue, and yellow flowers as well as perennial plants, as they commonly produce larger amounts of nectar (32). It is important to have sufficient vegetative biodiversity to ensure that a variety of blooms consistently occur throughout the life cycle of various species of bees. These can include flowering trees, shrubs, bunch grasses and other native plants.

Nesting and hibernation sites can be found underground, on the surface of the ground, in natural cavities, in compost piles, and in manmade structures such as walls or bird houses. However, it is important to maintain sufficient areas of land that are free from disturbances like planting, fire, tilling, mowing, and grazing. Population support for rodents should also be maintained, as they are beneficial providers of nesting sites for the bees (33). Furthermore, location of potential bumble bee nesting sites should maintain a distance of at least .6 miles (1 km) from honey bee hives in order to reduce competition and spread of disease.

Studies indicate that the flight distance of bumble bees from the nest to forage sites range from 900 feet (275 m) to one half of a mile (750 m) with a maximum flight distance of 7 miles (12 km) (20)(5)(21). This capacity for travel distance is quite farther than most other native bee species. However, as longer flights require more energy and time to accomplish, fewer resources will be available for offspring when bees are required to travel far distances for forage. Consequently, reduced distances for forage are optimal. Studies have suggested that between 800 and 2,500 acres of quality habitat are required for sufficient bumble bee population support. Furthermore, habitat fragmentation results in isolated patches unsuitable for supporting healthy bee colonies (11). Consequently, a connected, large-scale network of conserved pollinator habitat is necessary for long-term protection of the remaining native pollinator populations.

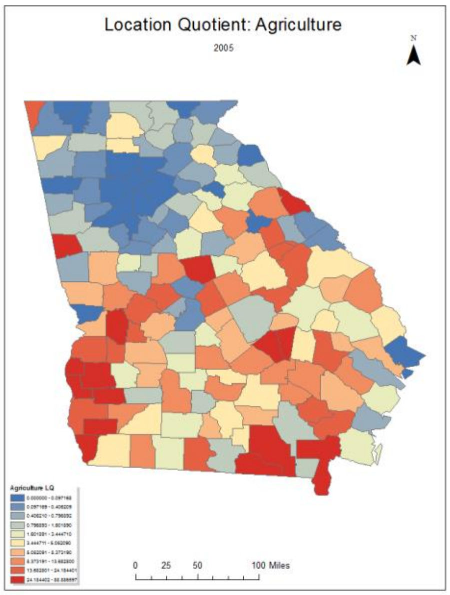
Data and Methods

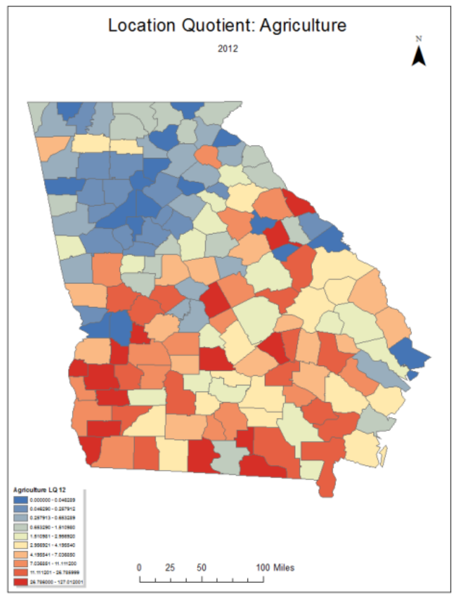
This paper uses the Metro Atlanta area in the state of Georgia as the study site in determining the most suitable location for a connective pollinator corridor. A suitability analysis assessing socioeconomic trends, land cover typology, biodiversity, predicted rodent habitat, conservation lands, and proximity to undisturbed rights-of-way was conducted in order to identify potential areas to restore or conserve as pollinator habitat.

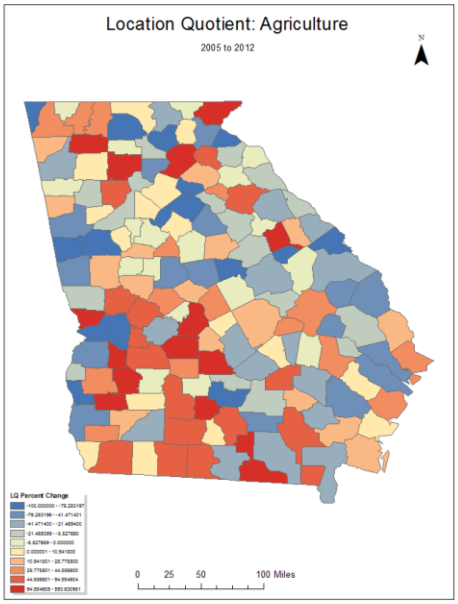
In order to assess where significant economic expansion was occurring for the agricultural industry, location quotients were calculated using data from the United States Census Bureau and American FactFinder. Data was imported into Excel and manipulated through the ArcGIS interface to produce joined attribute tables that could provide clean data regarding state and county agricultural employment as well as total employment for the years 2005 and 2012. These data were manipulated by python scripts in order to display employment numbers in the form of integers.

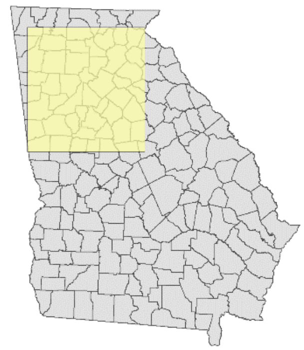
Socioeconomic GIS analysis was used to locate areas whose location quotients for agricultural activity have increased the most in the metro Atlanta region. Data was used from 2005 and 2012 to observe which location quotients have undergone the most dramatic increases in the last ten years. This type of development, whether it is comprised of cattle, corn, or insect-pollinated crops, has a variety of negative implications for our native pollinators. Foremost is the issue of habitat loss due to agricultural intensification and human activity, followed by the widespread use of pesticides. Habitat loss is a primary cause of native invertebrate pollinator species decline, as pollinators rely on biologically diverse natural habitat for survival. Hall and Cherokee counties were among the top ten counties with the highest increases in location quotients for the agriculture industry near the Metro Atlanta area, so the study focused on a geographic scope that included these areas.

Figures 1 and 2. Location Quotient Analyses and Eventual Scope





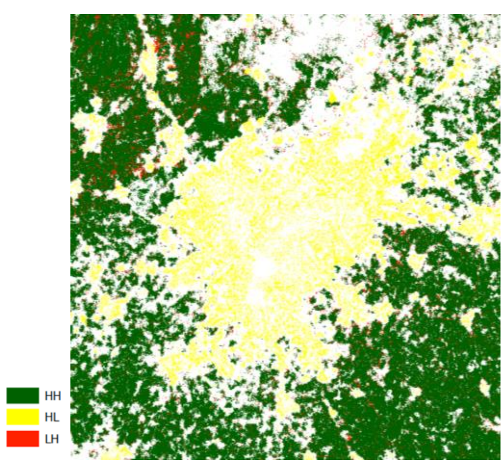




Land cover typology from the USDA Geospatial Data Gateway was important in the analysis for determining the location and quantity of potential invertebrate pollinator habitat and forage sources. The land cover dataset included 15 coverage types, including open water, developed open space, developed low intensity, developed medium intensity, developed high intensity, barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, herbaceous, hay/pasture, cultivated crops, woody wetlands, and emergent wetlands. In the analysis, preference was given to natural areas. As pollinators and their floral food sources are mutually dependent on each other for reproductive success, habitat biodiversity is a critical element in promoting invertebrate pollinator abundance and diversity. To account for this landscape quality, emphasis was placed on areas with greater current biodiversity by more heavily weighting the areas that included greater equal distributions of natural coverages. Furthermore, higher values were given to areas with higher proximity to permanently conserved lands and undisturbed rights-of-way. The weighted distance values were chosen based on research indicating that maximum bumblebee foraging distances are around 12 kilometers, while most bees stay within 1 to 2 kilometers (20)(5)(21).

The Georgia land cover raster was converted to polygons, where its 9 million+ features (15 land cover types) were assigned a suitability rating derived from interpretations of the literature. The land cover was then run through the ArcGIS Cluster and Outlier Analysis (Anselin Local Moran's I) where statistically significant clusters of high suitability land covers (diversity clusters) were highlighted. A high positive Z score for a feature means that the surrounding features have similar values of either high values or low values. In the COType field created by the outlier analysis, HH indicates a statistically significant (0.05) cluster of high values and LL indicates a significant cluster of low values. In this case, the low values included high, medium, and low intensity residential as well as croplands. A low negative Z score represents a spatial outlier. With the COType field, one can identify whether a feature is of high value and is surrounded by low value features (HL) or if the feature is of low value and is surrounded by high values (LH). These represented clusters of biodiversity.

Figure 3. Local Moran's I Cluster Analysis Results



The biodiversity clusters were then clipped out (Figure 3), returned to raster form, reclassified, and entered into a weighted overlay. Two polygon layers, one for conserved lands and another for undisturbed rights of way, had their Euclidean distances calculated with a standard cell size (30, same as original raster), were reclassified and entered into the weighted overlay. The final addition to the weighted overlay was the original Georgia land cover raster. The significance given to each factor was 30%, 25%, 25%, 20%, respectively. The weighted overlay results were converted to points in order to be processed by the ArcGIS Inverse Distance Weighted multivariate interpolation tool, which provides a representation of significant spatial trends.

Figure 4. Left: Euclidean Distance from Rights-of-Way; Right: Euclidean Distance from Conservation Lands

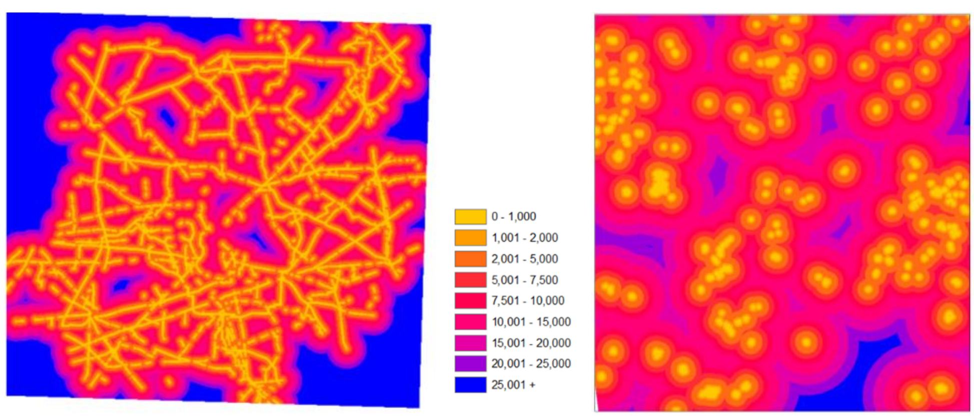


Figure 5. Weighted Overlay

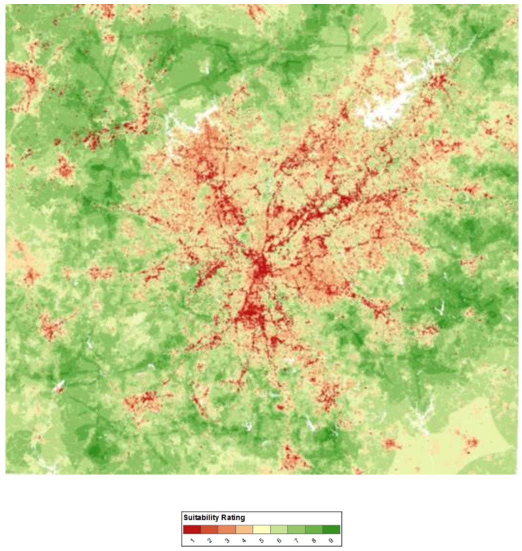
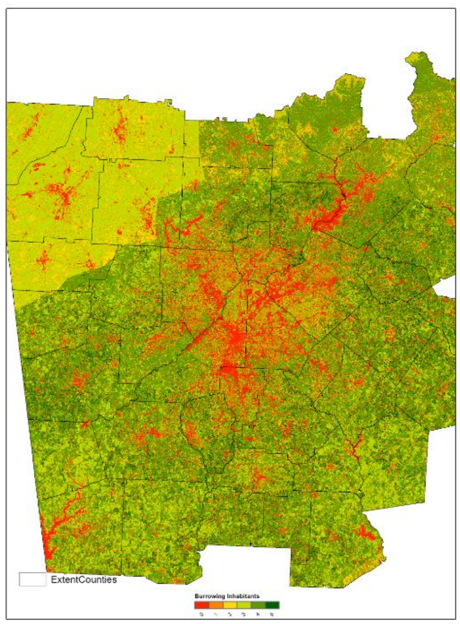


Figure 6. Predicted Habitat for Burrowing Mammals



The weighted overlay was then amended to take into account five mammal habitat models comprised of binary grids indicating predicted habitat in Georgia and areas not predicted to be habitat. These species were chosen based on bumblebee habitat and nesting requirements. The mammals consisted of the Eastern Mole, the Northern Short-Tailed Shrew, the Oldfield Mouse, the Southeastern Shrew, and the Woodland Vole. These species represent common yet regionally diverse species in order to simulate accurate environmental conditions. Cell statistics were used to calculate more ideal habitat based on greater predicted diversity and abundance of burrowing mammal occupancy (Figure 6). Areas with higher values were weighted more heavily in the weighted overlay.

After performing this function, areas of highest value (8 to 10) were isolated and areas of maximal acreage were identified (Figure 7). The literature suggests 800 acres as a minimum for population support so these areas were identified first. Adjacent sites of medium value were identified as potential restoration sites to increase the area of high value land less than 800 acres (Figure 8). Finally, the restoration candidates and high value lands were combined to produce a network of potential connective pollinator corridors (Figure 9).

Figure 7. High Value Land Greater than 800 Acres

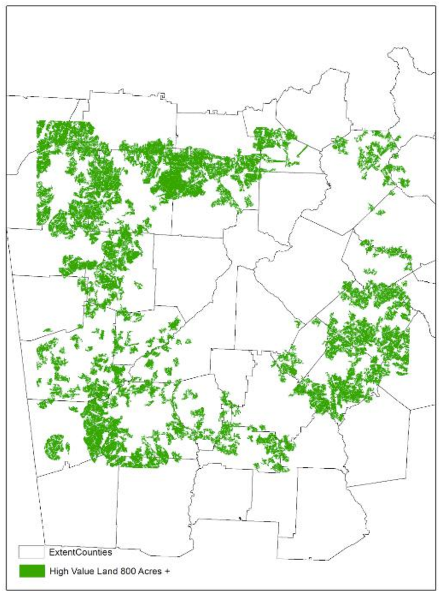


Figure 8. Restoration Candidates Adjacent to Fragmented High Value Land

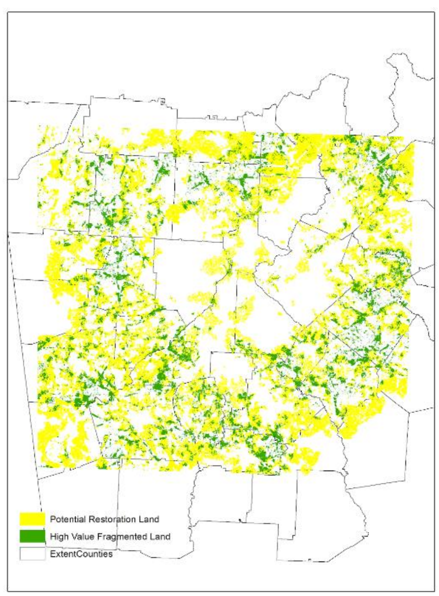
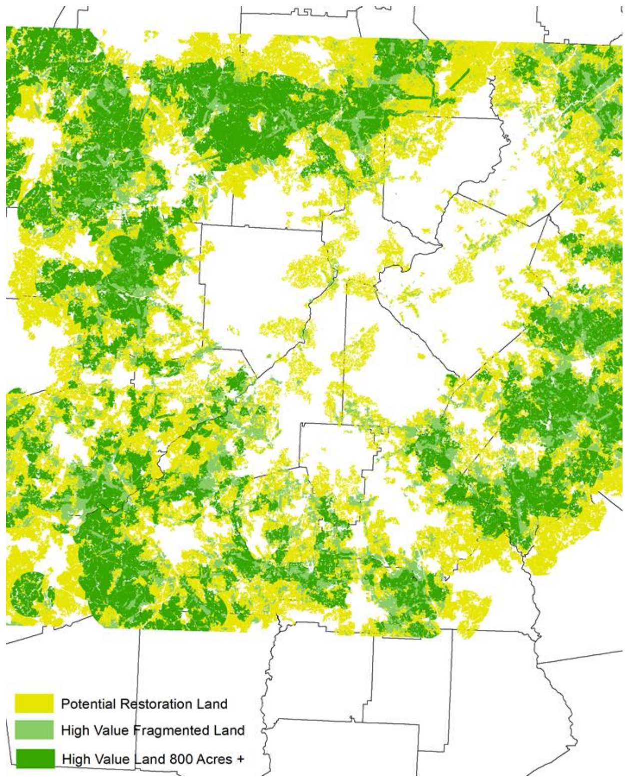


Figure 9. Pollinator Corridor Results



Results

Clear connective patterns can be identified and the opportunity to re-nourish or maintain them may not last long. The analysis identified several potential habitat corridors throughout the region, many of which would promote connectivity between established permanently protected lands. There also appears to be significant connectivity along the rights-of-way which spread throughout the region, which in some cases connects multiple separate preserved lands. Not only do the results identify many existing potential areas for pollinator corridor classification, they illuminate a spectrum of potential candidates for restoration projects. The weighted overlay output displays finer details regarding habitat suitability, displaying least suitable areas in red and most suitable areas in green, while the IDW results show where habitat suitability trends lie that may not be apparent upon closer speculation. The species-habitat associations and predicted burrowing mammal habitat models allowed us to further identify biologically diverse areas which may additionally satisfy nesting and overwintering requirements of native bumble bees.

These results show apparent biodiversity and habitat suitability trends throughout the study area. This model could be an important tool for identifying protection and restoration areas in locations that are more rapidly becoming agricultural areas, as habitat loss due to agricultural intensification is a primary culprit in the decline of invertebrate pollinator populations as well as the plants on which they thrive. Assessing areas that are at higher risk of agricultural intensification and habitat loss allows us to take measures to protect the ecological systems from becoming monoculture cropland or overgrazed pasture. These outputs may be able to inform policy and land conservation efforts in order to make more pollinator friendly land use decisions and protect our pollinator populations.

Discussion

Habitat suitability analysis for pollinators is not plentiful, as most research done on invertebrates involves spatial analyses of swarming insects and vectors of human disease. Remote sensing and GIS can provide rough estimates of potential habitat for pollinators when their environmental preferences are well understood, yet field data remains important for purposes of validating and training analyses. This study used habitat heterogeneity as a proxy for biodiversity and assumed that, based on nesting preferences cited in literature, spatial autocorrelation may exist between bumble bees and five Georgia mammal species. These may or may not be accurate assumptions and the assessment would benefit from validation by ground studies. Furthermore, in an attempt to create a pollinator corridor that satisfies a wide range of species, the unique preferences of specialist Bombus species are not addressed. This generalization could bias suitability results and limit predictive accuracy.

In terms of policy, restrictions and regulations on the importation of non-native bees for managed pollination services may be beneficial in limiting habitat competition and pathogen transmission. As of now, the only states with these types of restrictions are Oregon and California. Best management practices suggest avoiding the purchase of non-native commercial bees entirely and restricting native commercial bee use to greenhouses. Preventing the interaction of commercial bees with wild bumble bees is important, as is distancing honey bee hives from bumble bee habitats and other ecologically rare or sensitive areas. As no spatial data regarding commercial honey bee hives could be found for this study, proximity to bumble bee habitat could not be taken into account. Future studies could be undertaken regarding this matter as well as habitat changes over time and exposure to pesticides via point sources or runoff. Furthermore, improved policies regarding pesticide and herbicide use is badly needed.

Remote sensing and GIS analyses can provide valuable information regarding habitat suitability and assist conservation and development planning when field studies are not possible. It is important that urban planners and policy makers have tools to assist in identifying and restoring or maintaining sensitive natural areas; if decision makers do not feel that they are capable of successfully pursuing such efforts, meaningful attempts at conservation may not be likely to occur. Geographic information systems and habitat suitability modeling can inform decisions regarding where and how development should or should not occur as well as aid in the designation of protected lands. Land trusts, conservation easements, and other means of conservation can be used to protect sensitive pollinator areas. In agricultural areas, benefits can be gained by designated a proportionate amount of adjacent lands as unadulterated, year-round pollinator habitat. Furthermore, there are currently no bees listed under the Endangered Species Act despite the critically imperiled nature of several species. The inclusion of bumble bees on the list could offer real benefits in the form of federal protection, habitat conservation plans, safe harbor agreements, candidate conservation agreements, and conservation banks. This paper illustrates one attempt at using common planning tools to make conservation pursuits for native pollinators accessible to urban planners, policy makers, and the general public.

Further Reading

Native plant combinations which are highly attractive to bumble bees and provide year-round forage resources have been identified by groups like the Xerces Society for Invertebrate Conservation. Be sure to choose seeds that are free of pesticide coatings; these chemicals can be consumed by pollinators though guttation fluid when visiting blooms.

Southeast

(Alabama, Arkansas, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia)

Plant		Bloom Period and Color							
Common name	**Scientific name**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
Wild azalea	*Rhododendron canescens*								
Spotted beebalm	*Monarda punctata*								
Sundial lupine	*Lupinus perennis*								
Swamp rose	*Rosa palustris*								
Butterflyweed	*Asclepias tuberosa*								
Common buttonbrush	*Cephalanthus occidentalis*								
Field thistle	*Cirsium discolor*								
Narrowleaf mountain mint	*Pycnanthemum tenuifolium*								
Tall blazing star	*Liatris aspera*								
Great blue lobelia	*Lobelia siphilitica*								

Nationwide Small Trees and Shrubs

(E = east of the Rockies; W = west of the Rockies; no mark = nationwide)

Plant		Bloom Period and Color				
Common name	**Scientific name**	**Spring**	**Early Summer**	**Mid Summer**	**Late Summer**	**Fall**
Willow	*Salix* spp.					
New Jersey tea (E)	*Ceanothus americanus*					
Rhododendron	*Rhododendron* spp.					
Redbud	*Cercis* spp.					
Twinberry honeysuckle (W)	*Lonicera involucrata*					
Raspberry	*Rubus* spp.					

Nationwide Garden Plants

(Note that many of these are not natives, so should not be used outside of gardens or formal landscaping.)

Plant		Bloom Period and Color				
Common name	**Scientific name**	**Spring**	**Early Summer**	**Mid Summer**	**Late Summer**	**Fall**
Beardtongue/penstemon	*Penstemon* spp.					
Lupine	*Lupinus* spp.					
Borage	*Borago officinalis*					
Catnip	*Nepeta* spp.					
Coneflower	*Echinacea* spp.					
Rosemary	*Rosmarinus* spp.					
Russian sage	*Perovskia atriplicifolia*					
Oregano	*Origanum* spp.					
Red clover	*Trifolium pratense*					
Sunflower	*Helianthus annus*					
Lavender	*Lavandula* spp.					
Goldenrod	*Solidago* spp.					

Source: The Xerces Society for Invertebrate Conservation

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